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(54) **SENSOR STRUCTURE WITH PINNED STABILIZATION LAYER**

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G11B 5/39	(2006.01)
B82Y 25/00	(2011.01)
B82Y 10/00	(2011.01)

(52) **U.S. Cl.**
CPC ***G11B 5/3932*** (2013.01); *B82Y 10/00* (2013.01); *B82Y 25/00* (2013.01); *G11B 2005/3996* (2013.01); *Y10S 977/934* (2013.01); *Y10S 977/943* (2013.01)

(58) **Field of Classification Search**
CPC G11B 2005/3996; G11B 5/33; G11B 5/39; G11B 5/3903; G11B 5/3909; Y10S 977/934; Y10S 977/943; B82Y 25/00; B82Y 10/00
USPC 360/324.11, 319
See application file for complete search history.

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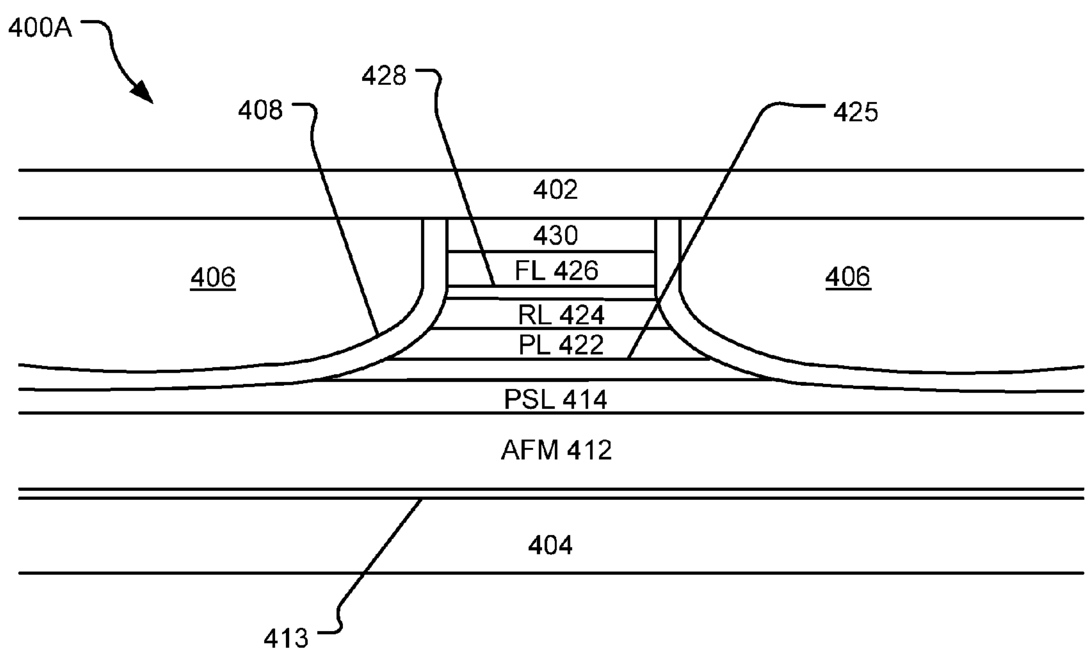
(57) **ABSTRACT**

A reader sensor that has a sensor stack with an AFM layer, a pinned stabilization layer, and a pinned layer, with the pinned stabilization layer closer to the AFM layer than to the pinned layer. The stack also includes a non-magnetic spacer layer between and in contact with the pinned stabilization layer and with the pinned layer. A magnetic coupling between the pinned stabilization layer and the pinned layer is no more than 50% of a magnetic coupling between the pinned stabilization layer and the AFM layer.

18 Claims, 5 Drawing Sheets



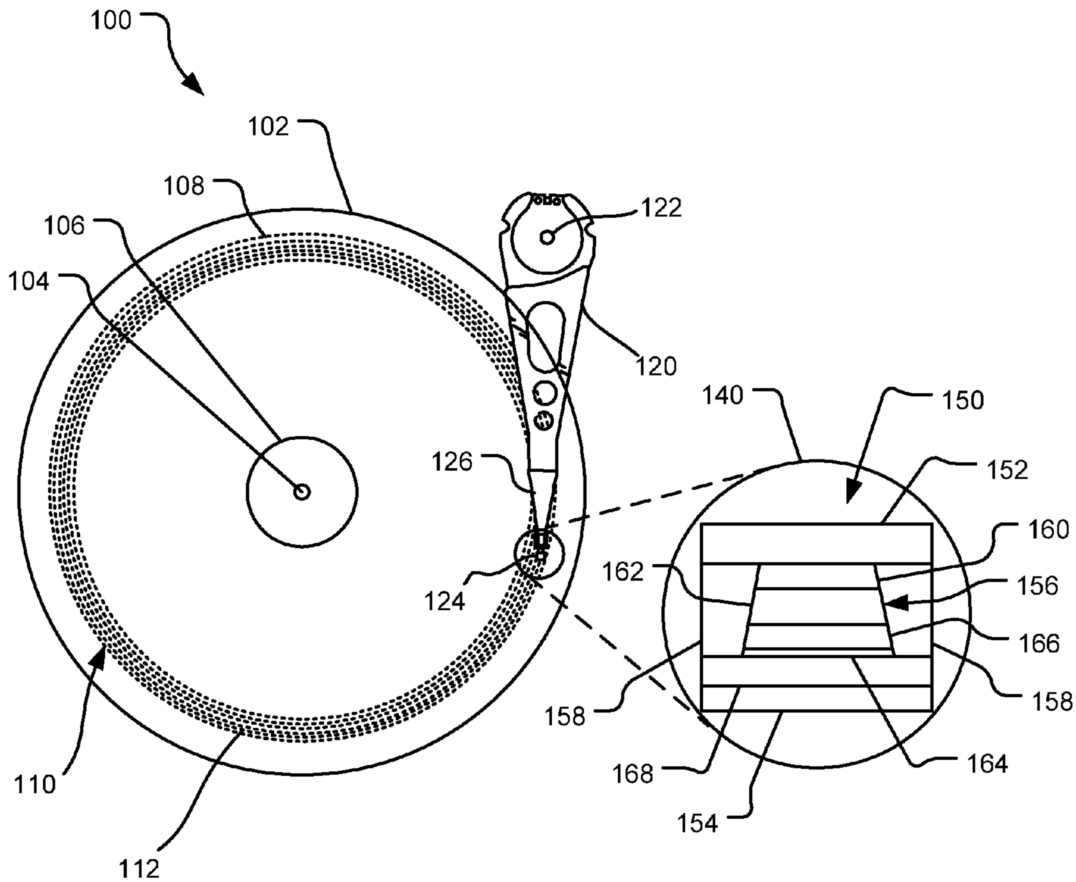

100
102
108
106
104
122
120
140
150
152
160
162
156
126
124
166
158
158
110
168
164
154
112

FIG. 1

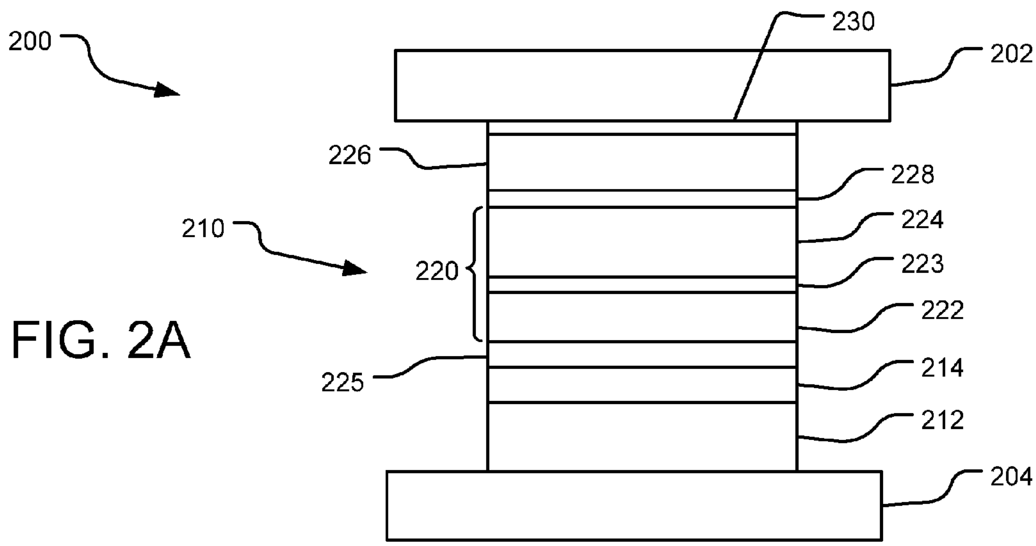

200
230
202
226
228
210
224
220
223
222
214
225
212
204

FIG. 2A

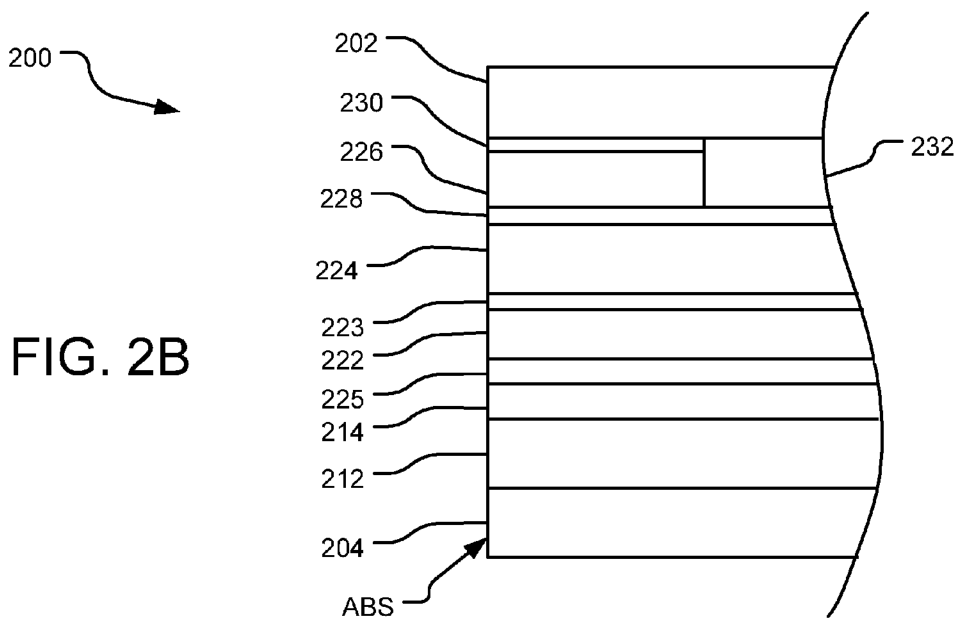

200
202
230
226
232
228
224
223
222
225
214
212
204
ABS

FIG. 2B

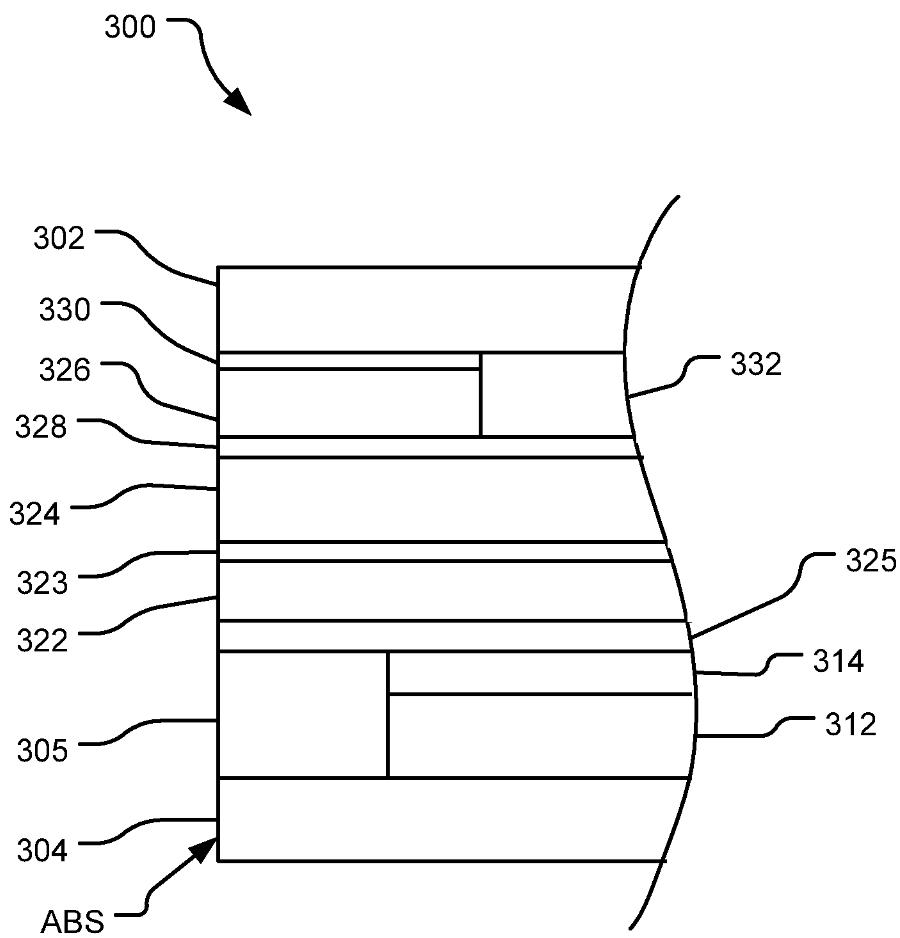


FIG. 3

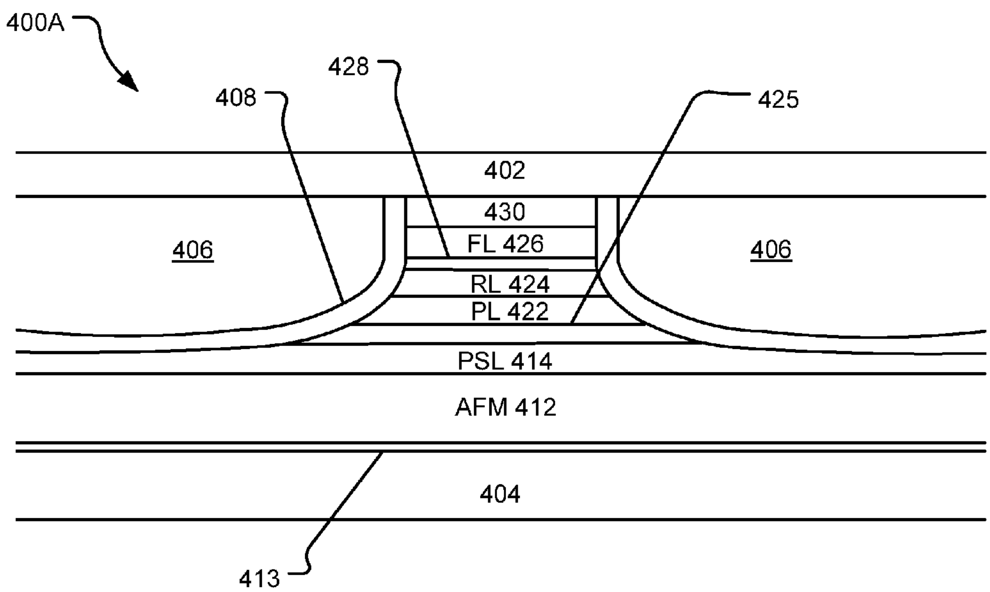

400A
428
408
425
402
430
406
FL 426
406
RL 424
PL 422
PSL 414
AFM 412
404
413

FIG. 4A

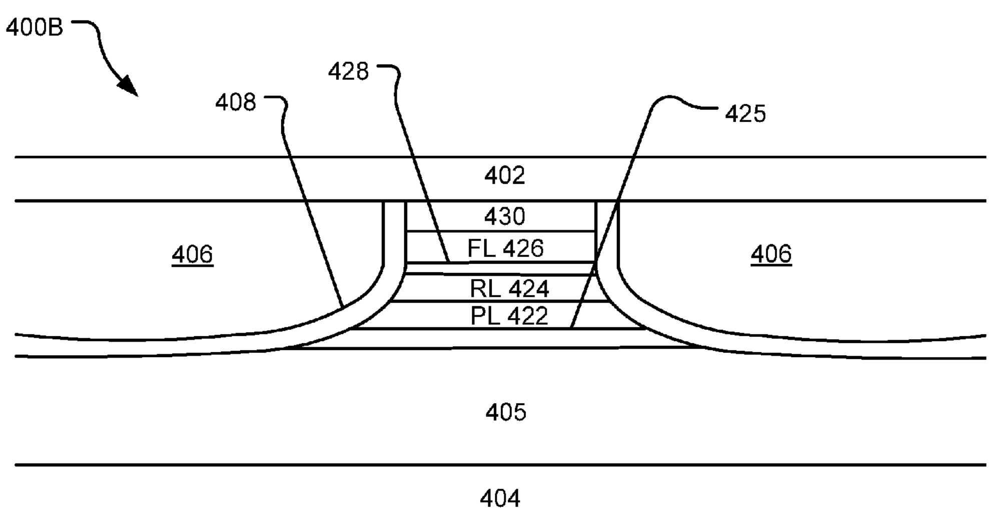

400B
428
408
425
402
430
406
FL 426
406
RL 424
PL 422
405
404

FIG. 4B

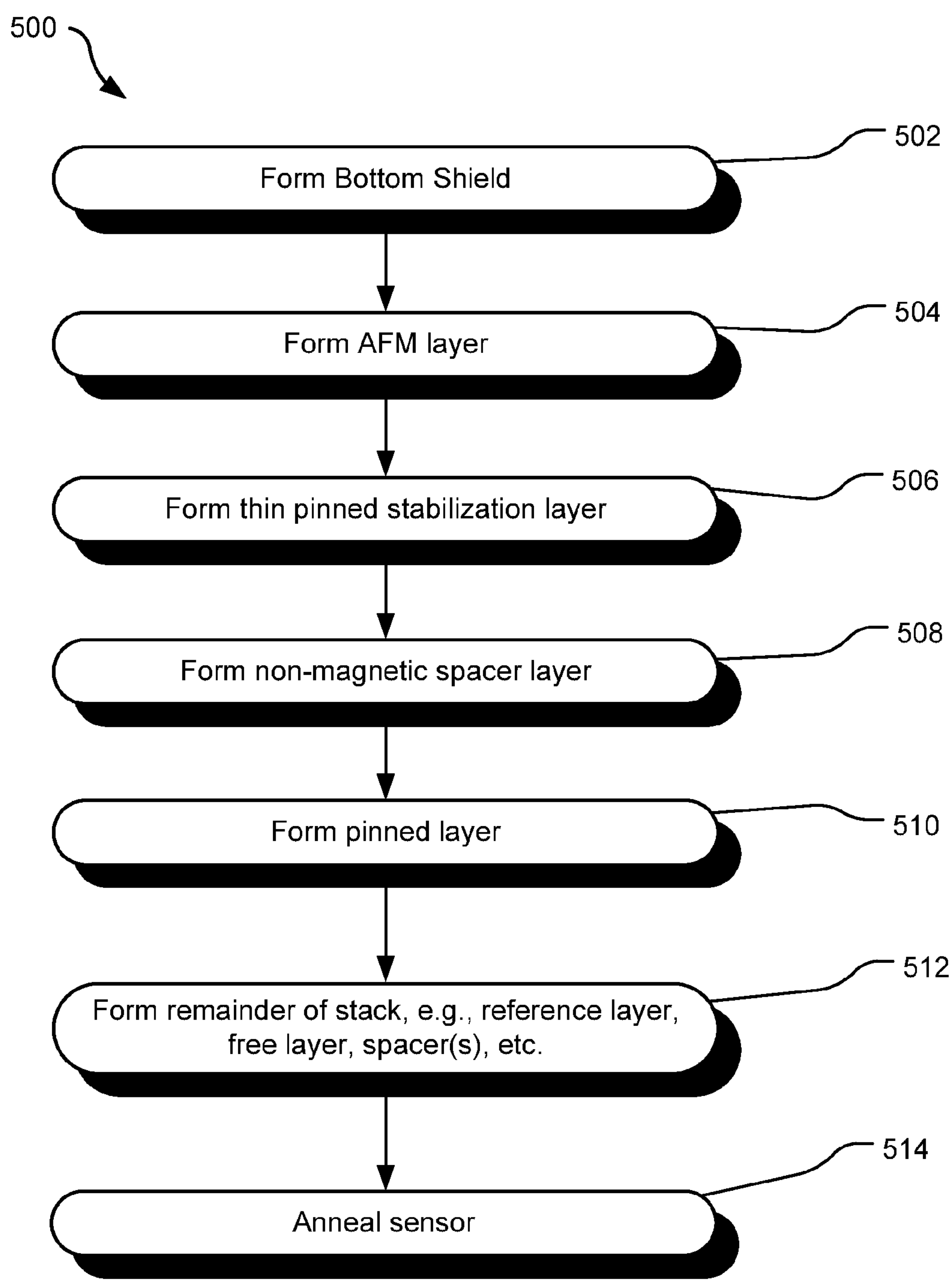

500
502
Form Bottom Shield
504
Form AFM layer
506
Form thin pinned stabilization layer
508
Form non-magnetic spacer layer
510
Form pinned layer
512
Form remainder of stack, e.g., reference layer, free layer, spacer(s), etc.
514
Anneal sensor

FIG. 5

SENSOR STRUCTURE WITH PINNED STABILIZATION LAYER

BACKGROUND

In a magnetic data storage and retrieval system, a magnetic read/write head includes a reader portion having a magnetoresistive (MR) sensor for retrieving magnetically encoded information stored on a magnetic disc. Magnetic flux from the surface of the disc causes rotation of the magnetization vector of a sensing layer of the MR sensor, which in turn causes a change in electrical resistivity of the MR sensor. The change in resistivity of the MR sensor can be detected by passing a current through the MR sensor and measuring a voltage across the MR sensor. External circuitry then converts the voltage information into an appropriate format and manipulates that information to recover the information encoded on the disc.

SUMMARY

One particular implementation described herein is a reader sensor stack having an antiferromagnetic material (AFM) layer, a pinned stabilization layer, a pinned layer, with the pinned stabilization layer closer to the AFM layer than to the pinned layer, a non-magnetic spacer layer between and in contact with the pinned stabilization layer and with the pinned layer, and a reference layer. A magnetic coupling between the pinned stabilization layer and the pinned layer is no more than 50% of a magnetic coupling between the pinned stabilization layer and the AFM layer.

Another particular implementation is a reader sensor stack having an AFM layer, a pinned stabilization layer having a thickness no greater than 2 nm, a pinned layer, with the pinned stabilization layer being closer to the AFM layer than the pinned layer, and a non-magnetic spacer layer between and in contact with the pinned stabilization layer and the pinned layer. The spacer layer provides no more than 0.15 erg/cm^2 magnetic coupling between the pinned stabilization layer and the pinned layer.

Yet another particular implementation is a reader sensor stack having an AFM layer, a pinned stabilization layer, a pinned layer, with the pinned stabilization layer between the AFM layer and the pinned layer, and a non-magnetic spacer layer between and in contact with the pinned stabilization layer and with the pinned layer. The pinned stabilization layer has a thickness of no more than 1.5 nm.

This Summary is provided to introduce a selection of concepts in a simplified form that are further described below in the Detailed Description. This Summary is not intended to identify key features or essential features of the claimed subject matter, nor is it intended to be used to limit the scope of the claimed subject matter. These and various other features and advantages will be apparent from a reading of the following detailed description.

BRIEF DESCRIPTIONS OF THE DRAWING

The described technology is best understood from the following Detailed Description describing various implementations read in connection with the accompanying drawings.

FIG. **1** is a perspective view of an example recording device using a reader having a sensor structure disclosed herein.

FIG. **2**A is a schematic of an air-bearing surface (ABS) view of an example reader sensor structure; FIG. **2**B is a schematic of a cross-section view taken orthogonal to the ABS of the example reader sensor structure.

FIG. **3** is a schematic of a cross-section view taken orthogonal to the ABS of another example reader sensor structure.

FIG. **4**A is an alternate schematic of an ABS view of an example reader sensor structure; FIG. **4**B is another alternate schematic of an ABS view of an example reader sensor structure.

FIG. **5** is a flowchart illustrating an example method of forming an example reader sensor structure.

DETAILED DESCRIPTION

There is an increasing demand for high data densities and sensitive sensors to read data from a magnetic media. Giant Magnetoresistive (GMR) sensors commonly consist of three magnetic layers, one of which is a soft magnet, separated by a thin conductive, non-magnetic spacer layer such as copper, from the other magnetic layers. Tunnel Magnetoresistive (TMR) sensors provide an extension to GMR in which the electrons travel perpendicularly to the layers across a thin insulating tunnel barrier.

In general, for these magnetoresistive (MR) sensors, an antiferromagnetic material (AFM) layer (often called the "pinning layer") is placed adjacent to the first magnetic layer to prevent it from rotating. AFM materials exhibiting this property are termed "pinning materials". With its rotation inhibited by the AFM layer, the first layer is termed the "pinned layer" (PL). A soft magnetic layer rotates freely in response to an external field and is called the "free layer" (FL). A coupling spacer layer between the PL and the third magnetic layer, a reference layer (RL), provides an antiferromagnetic coupling (e.g., an RKKY coupling) between them, forming a synthetic antiferromagnetic (SAF) structure. The MR sensor can include other (e.g., non-magnetic) layers.

To operate the MR sensor properly, the sensor is preferably stabilized against the formation of edge domains because domain wall motion results in electrical noise that makes data recovery difficult. A common way to achieve stabilization is with a permanent magnet abutted junction design. In this scheme, permanent magnets with high coercive field (i.e., hard magnets) are placed at each end of the sensor. The field from the permanent magnets stabilizes the sensor and prevents edge domain formation, as well as provides proper bias. Another common way to provide the free layer bias is to use stabilized soft magnetic layers in place of the permanent magnets. The use of the AFM allows for consistent and predictable orientation of the SAF structure. Furthermore, the use of the SAF structure stabilized by the AFM layer enables high amplitude linear response for a reader using the MR sensor.

During operation of the MR sensor, individual AFM grains may reorient their magnetic orientation, leading to degraded reader stability and possibly to sensor error. A reduction of the exchange coupling at the AFM/PL interface may increase the reader stability by reducing the effect of the AFM grain reorientation, as long as sensor polarity is maintained. A decreased coupling at the AFM/PL interface lowers the reader's sensitivity to any AFM-induced instabilities and to any effects of magnetic dispersion that are inherently present in the AFM layer. However, one relies on the interface exchange to magnetically align the AFM grains during the high-temperature setting anneal process. As-deposited, the individual grains in the AFM layer are randomly oriented in the film plane. During the annealing process, the grains are magnetically oriented by the torque provided by the adjacent PL, which follows the external magnetic field applied during the process. However, a weaker exchange between the AFM layer and the PL increases the energy barrier for the grain to orient and, as a consequence, leads to higher AFM dispersion. This higher dispersion may induce SAF/AFM instabilities and, in certain cases, result in the appearance of parts with opposite polarity.

An example sensor assembly disclosed herein provides a sensor stack design that combines good AFM grain setting while providing a weaker coupling to the SAF structure. The strength of coupling to the SAF structure is controllable and can be tuned to achieve a desired (e.g., optimal) sensor operation point. In addition to lowering the sensitivity to AFM-induced instabilities (e.g., reorientation of the magnetic orientation of a grain), this sensor stack design reduces the probability of the occurrence of these events, and improves stability of pinning against subsequent thermal anneals.

Specifically, the sensor assembly includes a reader "stack" having a pinned stabilization layer adjacent to and coupled to the AFM layer, and a non-magnetic spacer between the pinned stabilization layer and the PL. The spacer controls the coupling between the pinned stabilization layer and the PL, and provides a mechanism to reduce the effective coupling between the AFM layer and the PL, which in turn reduces the probability of transferring an instability from the AFM to the PL, and consequently, to the RL.

It is noted that in structures without a pinned stabilization layer, one would normally call a layer a "pinned layer" or PL when it is immediately next to an AFM layer that pins its magnetization. However, in this disclosure, the magnetic layer of the SAF structure closest to the AFM, even though it is only weakly coupled to the AFM (via the pinned stabilization layer) is nevertheless referred to as a "pinned layer" or PL.

In the following description, reference is made to the accompanying drawing that forms a part hereof and in which are shown by way of illustration at least one specific implementation. The following description provides additional specific implementations. It is to be understood that other implementations are contemplated and may be made without departing from the scope or spirit of the present disclosure. The following detailed description, therefore, is not to be taken in a limiting sense. While the present disclosure is not so limited, an appreciation of various aspects of the disclosure will be gained through a discussion of the examples provided below.

FIG. **1** illustrates a perspective view of an example recording device **100** (e.g., a disc drive assembly **100**) using a reader disclosed herein. Recording device **100** includes a disc **102**, which rotates about a spindle center or a disc axis of rotation **104** during operation. The disc **102** includes an inner diameter **106** and an outer diameter **108** between which are a number of concentric data tracks **110**, illustrated by circular dashed lines. The data tracks **110** are substantially circular and are made up of regularly spaced patterned bits **112**, indicated as dots or ovals on the disc **102**. It should be understood, however, that the described technology may be employed with various types of storage media, including continuous magnetic media, discrete track (DT) media, etc.

Information may be written to and read from the bits **112** on the disc **102** in different data tracks **110**. A transducer head **124** is mounted on an actuator assembly **120** at an end distal to an actuator axis of rotation **122** and the transducer head **124** flies in close proximity above the surface of the disc **102** during disc operation. The actuator assembly **120** rotates during a seek operation about the actuator axis of rotation **122** positioned adjacent to the disc **102**. The seek operation positions the transducer head **124** over a target data track of the data tracks **110**.

An exploded view **140** illustrates an expanded view of a portion of the transducer head **124**, with a reader sensor **150** illustrated by a schematic block diagram that illustrates an air-bearing surface (ABS) view of the reader sensor **150**. That is, the exploded view **140** illustrates a portion of the transducer head **124** that faces the ABS of the disc **102** when the disc drive assembly **100** is in use. Thus, the reader sensor **150** shown in the exploded view **140** may be rotated by about 180 degrees about an axis (e.g., about a z-axis) when operationally attached to the transducer head **124**. It is noted that the reader sensor **150** in the exploded view **140** is not necessarily illustrated with accurate dimensions and/or all of its elements, but rather, the pertinent features of the reader sensor **150**, relevant to the current disclosure, are shown.

In the illustrated implementation, the reader sensor **150** is illustrated to include a top shield structure **152** and a bottom shield **154**, with a sensor stack **156** between the shields **152**, **154** along the down-track direction of the reader sensor **150**. The top shield structure **152** and the bottom shield **154** protect the sensor stack **156** from flux from adjacent data tracks **110** on the disc **102**. Top shield structure **152** provides stabilization to side shields **158** that are placed between the top shield **152** and the bottom shield **154**, bounding the sensor stack **156** in the cross-track direction.

Although not shown in detail nor with relative dimensions in the exploded view **140**, sensor stack **156** includes multiple layers, including a free layer **160** that has a switchable magnetic orientation. The sensor stack **156** also includes a synthetic antiferromagnetic (SAF) structure **162**, a pinned stabilization layer **164**, and a non-magnetic spacer layer **166** between the SAF structure **162** and the pinned stabilization layer **164**. An antiferromagnetic (AFM) layer **168** is between the bottom shield **154** and the pinned stabilization layer **164**. Not shown, a seed layer may be present between the bottom shield **154** and the AFM layer **168**.

Not seen in the exploded view **140**, the SAF structure **162** includes at least a reference layer and a pinned layer with a spacer layer therebetween, with the pinned layer being adjacent to the spacer layer **166**. The sensor stack **156** thus has two pinned layers, the pinned stabilization layer **164** adjacent to the AFM layer **168** and the pinned layer in the SAF structure **162**, with the non-magnetic spacer layer **166** therebetween.

The pinned stabilization layer **164** is a thin (i.e., less than 5 nm thick) layer having a pinned magnetization. The pinned stabilization layer **164** is in physical contact with and magnetically coupled to the AFM layer **168**. The high exchange coupling at the interface of the AFM layer **168** and the pinned stabilization layer **164** enables adequate magnetic setting of the grains of the material forming the AFM layer **168** during an anneal process used in the forming of the reader sensor **150**.

FIG. **2**A illustrates an ABS view of an example implementation of a sensor structure having a pinned stabilization layer between another pinned layer and an AFM layer, and FIG. **2**B is a view orthogonal to the ABS view of FIG. **2**A. In FIGS. **2**A and **2**B, a reader **200** includes a top shield structure **202** and a bottom bulk shield **204** on two opposite sides (along the down-track direction) of a sensor stack **210** that has multiple layers. Not illustrated in this figure but seen in FIG. **1**, side shields are present around the sensor stack **210** in the cross-track or lateral direction, between the top shield structure **202** and the bottom shield **204**. In the illustrated implementation, the side shields would encompass all of the layers of the sensor stack **210**; in other implementations, for example, the side shields may not encompass one or more layers.

Proximate bottom bulk shield **204**, the sensor stack **210** includes an AFM layer **212**. Not shown, a seed layer may be present between the bottom shield **204** and the AFM layer **212**. Sensor stack **210** has a pinned stabilization layer **214** adjacent to and in contact with the AFM layer **212**, and also a SAF structure **220** composed of a pinned layer (PL) **222**, a reference layer (RL) **224** and a spacer layer **223** therebetween. The SAF structure **220** is arranged with the pinned layer **222** closer to the pinned stabilization layer **214** than the reference layer **224**. A spacer layer **225** is present between and in contact with both the pinned stabilization layer **214** and the SAF structure **220**. A free layer (FL) **226**, which has a switchable magnetization orientation, is proximate to the reference layer **224** of the SAF structure **220**, with a barrier layer **228** between the free layer **226** and the reference layer **224**. Also shown is a capping layer **230** and an isolation layer **232**.

The particulars of the specific construction of the reader sensor **200** are not of particular relevance to the pinned stabilization layer **214** in the reader sensor **200**, and a detailed discussion of the other elements of the reader sensor **200** is not provided herein. Unless indicated otherwise, the various layers of the reader sensor **200** are made from materials commonly used for those elements.

The magnetization of the pinned layer **222** in the SAF structure **220** is stabilized, to a certain extent, by the AFM layer **212**. However, due to the presence of the pinned stabilization layer **214** and the spacer layer **225**, the coupling is reduced, compared to if no pinned stabilization layer **214** and spacer layer **225** were present. This reduced coupling decreases the probability of transferring an instability from the AFM layer **212** to the pinned layer **222**.

As indicated above, the pinned stabilization layer **214** is a thin (i.e., no greater than 5 nm thick) layer having a pinned magnetization. In some implementations, the pinned stabilization layer **214** has a thickness no greater than 2 nm, in other embodiments no greater than 1.5 nm, and yet in other embodiments no greater than 1 nm. An example range for thicknesses of the pinned stabilization layer **214** is 0.5 to 1.5 nm. As a comparison, the pinned layer **222** typically has a thickness in the range of about 1.5 to 4 nm. The pinned stabilization layer **214** may be formed of the same or different material than the pinned layer **222**.

The spacer layer **225** between the pinned stabilization layer **214** and the pinned layer **222** enables the magnetic coupling (either ferromagnetic or antiferromagnetic coupling) between the pinned stabilization layer **214** and the pinned layer **222**. The spacer layer **225** is formed from a non-magnetic, electrically conductive material.

The magnetic coupling between the pinned stabilization layer **214** and the pinned layer **222** is less than the coupling between the AFM layer **212** and the pinned stabilization layer **214**, and less than the SAF coupling between the pinned layer **222** and the reference layer **224**. In many implementations, the coupling (per unit area) between the AFM layer **212** and the pinned stabilization layer **214** is comparable to the SAF coupling. The magnetic coupling between the pinned stabilization layer **214** and the pinned layer **222** can be as much as 10-20 times less than the lesser of the other two couplings (i.e., between the AFM layer **212** and the pinned stabilization layer **214**, and between the pinned layer **222** and the reference layer **224**). The role of the magnetic coupling between the pinned stabilization layer **214** and the pinned layer **222** is to maintain the desired magnetic orientation of the SAF structure **220** of the reader **200**.

In some implementations, the magnetic coupling between the pinned stabilization layer **214** and the pinned layer **222** is no more than 50% of the magnetic coupling between the pinned stabilization layer **214** and the AFM layer **212**. In some implementations, the magnetic coupling between the pinned stabilization layer **214** and the pinned layer **222** is no more than 50% of the magnetic coupling between the pinned layer **222** and the reference layer **224**. That is, the spacer layer **225** reduces the magnetic coupling by at least half of one of the other two couplings. In some implementations, the coupling is reduced by at least 65%, or by at least 75%, or by at least 80%, or by at least 85%, or by at least 90% or even 95%; such reductions result in the coupling between the pinned stabilization layer **214** and the pinned layer **222** being no more than 35%, or no more than 25%, or no more than 20%, or no more than 15%, or no more than 10% or even no more than 5% of the coupling between the pinned stabilization layer **214** and the AFM layer **212** or the pinned layer **222** and the reference layer **224**, typically the lesser of the two.

In some implementations, the spacer layer **225** is formed of a material that supports RKKY coupling between the pinned stabilization layer **214** and the pinned layer **222**. Examples of materials that support RKKY coupling, and would be suitable for the spacer layer **225**, include ruthenium (Ru), iridium (Ir), and rhodium (Rh); these and other materials can provide ferromagnetic or antiferromagnetic RKKY coupling as a function of the thickness of the material layer. In other implementations, the coupling may be roughness-induced. The coupling between the pinned stabilization layer **214** and the pinned layer **222** can be either ferromagnetic or antiferromagnetic.

The pinned layer **222** is coupled (either ferromagnetically or antiferromagnetically) to the pinned stabilization layer **214** via the non-magnetic spacer layer **225**. As discussed above, this coupling can be of RKKY origin or can be roughness-induced. The magnitude and sign (i.e., positive (ferromagnetic) or negative (antiferromagnetic)) of the coupling can be controlled by the selection of the materials and thicknesses of the pinned stabilization layer **214**, the pinned layer **222** and the spacer layer **225**. In some implementations, the coupling between the pinned stabilization layer **214** and the pinned layer **222** is no more than 0.15 erg/cm^2, in other implementations no more than 0.1 erg/cm^2, and in yet others no more than 0.05 erg/cm^2. In some implementations, the coupling between the pinned stabilization layer **214** and the pinned layer **222** is 0.01-0.1 erg/cm^2, and in others 0.02-0.05 erg/cm^2.

A very thin pinned stabilization layer **214** is desired (e.g., less than 1.5 nm, or less than 1 nm) for various reasons. First, a thin layer **214** is desired because the thickness of every layer contributes to net shield-to-shield spacing (SSS) (i.e., the spacing between the top shield **202** and the bottom shield **204**), it is desired is to maintain a low SSS in order to achieve high linear density capability of the reader sensor **200**. Second, during processing of the sensor **200**, while a high field setting anneal does saturate the magnetization of a very thin stabilization layer **214**, subsequent lower field lower temperature anneals do not perturb it; this helps preserve the magnetic orientation of the AFM grains achieved during the stack anneal (i.e., the high field setting anneal) and widens the processing options for subsequent anneals. Third, by having the pinned stabilization layer **214** present, the stability of the AFM grains is improved due to the reduced destabilizing torque provided by the thin pinned stabilization layer, compared to a pinned layer without a pinned stabilization layer. For a thick pinned layer (usually 1.5 to 4 nm thick), the magnetization is relatively uniform; the torque exerted on an AFM grain that is oriented close to perpendicular to the direction of pinning is high and the barrier for switching is low. Conversely, magnetization of a very thin pinned layer, to a large degree, follows the local magnetic order of any individual AFM grain, and does not destabilize this grain.

Although the sensor **200** includes two additional layers (i.e., the pinned stabilization layer **214** and the spacer layer

225) over other sensors without these layers, it is possible to reduce the thickness of the SAF structure **220** to compensate for the increased SSS due to the two additional layers. Because the SAF structure **220** is only weakly coupled to the AFM layer **212**, the thickness of the SAF structure **220** can be reduced; in a sensor without the two additional layers (i.e., the pinned stabilization layer **214** and the spacer layer **225**), the pinned layer **222** and the reference layer **224** are thicker due to the need to suppress the dispersion originating at the AFM layer **212**.

FIG. **3** illustrates another schematic block diagram of a view orthogonal to the ABS view of an example implementation of a sensor structure having a pinned stabilization layer between another pinned layer and an AFM layer. Unless indicated otherwise, the elements of FIG. **3** are the same as or similar to like elements of FIGS. **2**A and **2**B.

A reader **300** includes a top shield structure **302** and a bottom bulk shield **304**. Proximate bottom bulk shield **304** is an AFM layer **312**; AFM layer **312** is recessed from the ABS and as such does not contribute to an effective SSS. The recess or area voided by the recessed AFM layer **312** has a front shield **305**. Not shown, a seed layer may be present between the bottom shield **304** and the AFM layer **312**. A pinned stabilization layer **314** is adjacent to and in contact with the AFM layer **312**; pinned stabilization layer **314** is also recessed from the ABS, and as such does not contribute to an effective SSS. The recess or area voided by the pinned stabilization layer **314** has a front shield **305**. Reader **300** also has a pinned layer (PL) **322**, a reference layer (RL) **324** and a spacer layer **323** therebetween. A spacer layer **325** is present between and in contact with both the pinned stabilization layer **314** and the pinned layer **322**. A free layer (FL) **326**, which has a switchable magnetization orientation, is proximate to the reference layer **324**, with a barrier layer **328** between the free layer **326** and the reference layer **324**. Also shown is a capping layer **330** and an isolation layer **332**.

FIGS. **4**A and **4**B illustrate two other schematic block diagram of an ABS view of example implementations of sensor structures having a pinned stabilization layer between another pinned layer and an AFM layer. Unless indicated otherwise, the elements of FIG. **4**A are the same as or similar to like elements of FIGS. **2**A, **2**B and the elements of FIG. **4**B are the same as or similar to the like elements of FIG. **3**.

In both FIGS. **4**A and **4**B, a reader **400**A, **400**B, respectively, includes a top shield structure **402** and bottom bulk shield **404** on two opposite sides (along the down-track direction) of a sensor stack that has multiple layers. Reader **400**A, **400**B includes side shields **406** on either side of the multi-layer sensor stack in the cross-track or lateral direction, between the top shield structure **402** and the bottom shield **404**. In the illustrated implementation, the side shields **406** encompass some, but not all, of the layers of the multi-layer sensor stack. A junction isolation layer **408** insulates the side shields **406** from the layers of the sensor stack.

In FIG. **4**A, for reader **400**A, proximate bottom bulk shield **404**, the sensor stack includes an AFM layer **412** (AFM **412**) and a seed layer **413** between the bottom shield **404** and the AFM layer **412**. The sensor stack also has a pinned stabilization layer **414** (PSL **414**) adjacent to and in contact with the AFM layer **412**.

Reader **400**B in FIG. **4**B also includes an AFM layer and a seed layer between the bottom shield **404** and the AFM layer. The sensor stack also has a pinned stabilization layer adjacent to and in contact with the AFM layer. However, in this implementation, the seed layer, the AFM layer, and the pinned stabilization layer are recessed from the ABS and hidden or otherwise blocked from the ABS view by a front shield **405**.

Both readers **400**A, **400**B also have a pinned layer **422** (PL **422**), a reference layer **424** (RL **424**) and a spacer layer (not shown) between the pinned layer **422** and the reference layer **424**. The pinned layer **422** is closer to the pinned stabilization layer **414** than the reference layer **424**. A spacer layer **425** is present between and in contact with both the pinned stabilization layer **414** and the pinned layer **422**. A free layer **426** (FL **426**), which has a switchable magnetization orientation, is proximate to the reference layer **424**, with a barrier layer **428** between the free layer **426** and the reference layer **424**. Also shown is a capping layer **430**.

The pinned layer **422** is coupled (either ferromagnetically or antiferromagnetically) to the pinned stabilization layer **414** via the non-magnetic spacer layer **425**. The spacer layer **425** between the pinned stabilization layer **414** and the pinned layer **422** provides the magnetic coupling (either ferromagnetic or antiferromagnetic coupling) between the pinned stabilization layer **414** and the pinned layer **422**. The magnitude and sign (i.e., positive (ferromagnetic) or negative (antiferromagnetic)) of the coupling can be controlled by the selection of the materials and thicknesses of the pinned stabilization layer **414**, the pinned layer **422** and the spacer layer **425**.

All of the read sensors described above, e.g., readers **150**, **200**, **300**, **400**A, **400**B and variations thereof, and sensor stacks described above, e.g., stacks **156**, **210**, and variations thereof, can be fabricated by a combination of various methods, including plating, sputtering, vacuum deposition, etching, ion milling, and other deposition and processing techniques.

In reference to FIG. **5**, a flowchart illustrates an example method **500** for forming a read sensor having a sensor stack with a pinned stabilization layer and non-magnetic spacer layer between another pinned layer and an AFM layer. The method involves operation **502** of forming a bottom shield layer on a substrate. This operation does not require forming the bottom shield directly on the substrate, as intervening materials/layers may be present between the bottom shield and substrate. A sensor stack is formed on the bottom shield in operations **504** through **512**. This operation does not require forming the sensor stack directly on the shield, as intervening materials/layers (e.g., a seed layer) may be present between the bottom shield and sensor stack. In operation **504**, an antiferromagnetic layer (AFM) is formed. Directly on and in contact with the AFM layer, a pinned stabilization layer, having a thickness of no more than 5 nm, is formed in operation **506**. A non-magnetic spacer layer is formed in operation **508** directly on and in contact with the pinned stabilization layer, and a pinned layer is formed directly on and in contact with the non-magnetic spacer layer in operation **510**. The remainder of the sensor stack is formed in operation **512**, which includes forming layers such as a reference layer, a free layer, one or more spacer or barrier layers, and other layers. Any or all of operations **504** through **512** can be done in a single (e.g., deposition) step, or any number of the operations **504** through **512** may be combined; intervening operations may be present between any of the operations. For example, for sensor stacks having a recessed AFM layer and recessed pinned stabilization layer, operations **504** and **506** may be done as a single step, then a front shield can be defined, after which operations **508**, **510** and **512** are done as a single step.

After formation of the sensor stack, the reader sensor may be annealed in operation **514** under high temperature in the presence of a magnetic field.

The above specification and examples provide a complete description of the structure and use of exemplary implementations of the invention. The above description provides specific implementations. It is to be understood that other implementations are contemplated and may be made without departing from the scope or spirit of the present disclosure. The above detailed description, therefore, is not to be taken in a limiting sense. While the present disclosure is not so limited, an appreciation of various aspects of the disclosure will be gained through a discussion of the examples provided.

Unless otherwise indicated, all numbers expressing feature sizes, amounts, and physical properties are to be understood as being modified by the term "about." Accordingly, unless indicated to the contrary, the numerical parameters set forth are approximations that can vary depending upon the desired properties sought to be obtained by those skilled in the art utilizing the teachings disclosed herein.

As used herein, the singular forms "a", "an", and "the" encompass implementations having plural referents, unless the content clearly dictates otherwise. As used in this specification and the appended claims, the term "or" is generally employed in its sense including "and/or" unless the content clearly dictates otherwise.

Spatially related terms, including but not limited to, "bottom," "lower", "top", "upper", "beneath", "below", "above", "on top", "on," etc., if used herein, are utilized for ease of description to describe spatial relationships of an element(s) to another. Such spatially related terms encompass different orientations of the device in addition to the particular orientations depicted in the figures and described herein. For example, if a structure depicted in the figures is turned over or flipped over, portions previously described as below or beneath other elements would then be above or over those other elements.

Since many implementations of the invention can be made without departing from the spirit and scope of the invention, the invention resides in the claims hereinafter appended. Furthermore, structural features of the different implementations may be combined in yet another implementation without departing from the recited claims.

What is claimed is:

1. A reader sensor stack comprising:

an AFM layer;

a pinned stabilization layer having a thickness no greater than 1.5 nm and magnetically coupled to the AFM layer;

a pinned layer, with the pinned stabilization layer closer to the AFM layer than the pinned layer;

a non-magnetic spacer layer between and in contact with the pinned stabilization layer and with the pinned layer; and

a reference layer antiferromagnetically coupled to the pinned layer,

wherein a magnetic coupling between the pinned stabilization layer and the pinned layer is no more than 50% of the magnetic coupling between the pinned stabilization layer and the AFM layer.

2. The reader sensor stack of claim **1**, wherein the magnetic coupling between the pinned stabilization layer and the pinned layer is no more than 35% of the magnetic coupling between the pinned stabilization layer and the AFM layer.

3. The reader sensor stack of claim **1**, wherein the pinned stabilization layer is adjacent to and in contact with the AFM layer.

4. The reader sensor stack of claim **1**, wherein the non-magnetic spacer layer enables RKKY coupling.

5. The reader sensor stack of claim **1**, wherein the non-magnetic spacer layer comprises Ru, Ir, Rh or Ta.

6. The reader sensor stack of claim **1**, wherein the pinned stabilization layer has a thickness of no more than 1 nm.

7. The reader sensor stack of claim **1**, wherein the pinned stabilization layer has a thickness in the range of 0.5 to 1.5 nm.

8. A reader sensor stack comprising:

an AFM layer;

a pinned stabilization layer having a thickness no greater than 1.5 nm and magnetically coupled to the AFM layer;

a pinned layer, with the pinned stabilization layer being closer to the AFM layer than the pinned layer; a reference layer antiferromagnetically coupled to the pinned layer; and

a non-magnetic spacer layer between and in contact with the pinned stabilization layer and with the pinned layer, the spacer layer providing no more than 0.15 erg/cm^2 magnetic coupling between the pinned stabilization layer and the pinned layer.

9. The reader sensor stack of claim **8**, wherein the pinned stabilization layer is adjacent to and in contact with the AFM layer.

10. The reader sensor stack of claim **8**, wherein the non-magnetic spacer layer has RKKY coupling properties.

11. The reader sensor stack of claim **8**, wherein the spacer layer comprises Ru, Ir, Rh, or Ta.

12. The reader sensor stack of claim **8**, wherein the pinned stabilization layer has a thickness in the range of 0.5 to 1.5 nm.

13. The reader sensor stack of claim **8**, wherein the pinned stabilization layer has a thickness of no more than 1 nm.

14. The reader sensor stack of claim **8**, wherein the spacer layer provides no more than 0.1 erg/cm^2 magnetic coupling between the pinned stabilization layer and the pinned layer.

15. A reader sensor stack comprising:

an AFM layer;

a pinned stabilization layer magnetically coupled to the AFM layer;

a pinned layer, with the pinned stabilization layer between the AFM layer and the pinned layer; a reference layer antiferromagnetically coupled to the pinned layer;

a non-magnetic spacer layer between and in contact with the pinned stabilization layer and with the pinned layer,

wherein the pinned stabilization layer has a thickness of less than 1.5 nm and the pinned layer has a thickness greater than 1.5 nm, and the pinned stabilization layer and the pinned layer have a magnetic coupling therebetween of no more than 0.15 erg/cm^2.

16. The reader sensor stack of claim **15**, wherein the non-magnetic spacer layer enables RKKY coupling.

17. The reader sensor stack of claim **16**, wherein the spacer layer comprises Ru, Ir, or Rh.

18. The reader sensor stack of claim **15**, wherein the AFM layer and the pinned stabilization layer are recessed from an air-bearing surface of the reader sensor stack.

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